4.1 KINEMATICS OF SIMPLE HARMONIC MOTION
4.2 ENERGY CHANGES DURING SIMPLE HARMONIC MOTION
4.3 FORCED OSCILLATIONS AND RESONANCE *HW/Study Packet*

SL/HL	
<u>Required:</u> READ Hamper pp 100-114 Tsokos, pp 195-209	<u>Supplemental:</u> DO Tsokos pp 209-215, #9,10,13,18,20,26 READ Cutnell and Johnson, pp 285-302 (HL)

REMEMBER TO….

- ✓ *Work through all of the 'example problems' in the texts as you are reading them*
- ✓ *Refer to the* ***IB Physics Guide*** *for details on what you need to know about this topic*
- ✓ *Refer to the* ***Study Guides*** *for suggested exercises to do each night*
- ✓ *First try to do these problems using only what is provided to you from the* ***IB Data Booklet***
- ✓ *Refer to the solutions/key ONLY after you have attempted the problems to the best of your ability*

UNIT OUTLINE

I. DEFINING TERMS
- A. HOW OSCILLATIONS 'ARE' WAVES

II. EQUATIONS OF SHM
- A. DISPLACEMENT AND VELOCITY
- B. ACCELERATION - THE DEFINING EQUATION OF SHM

III. ENERGY IN SHM

IV. DAMPING
- A. ENERGY LOSS IN SHM
- B. DEGREES AND TYPES OF DAMPING

V. RESONANCE
- A. FORCED OSCILLATIONS AND RESONANCE
- B. 'GOOD' AND 'BAD' RESONANCE

FROM THE IB DATA BOOKLET

$$\omega = \frac{2\pi}{T}$$

$x = x_0 \sin \omega t$; $x = x_0 \cos \omega t$

$v = \pm\omega\sqrt{(x_0{}^2 - x^2)}$

$E_{K(max)} = \frac{1}{2} m\omega^2 x_0{}^2$

$v = v_0 \cos \omega t$; $v = -v_0 \sin \omega t$

$E_K = \frac{1}{2} m\omega^2 (x_0{}^2 - x^2)$

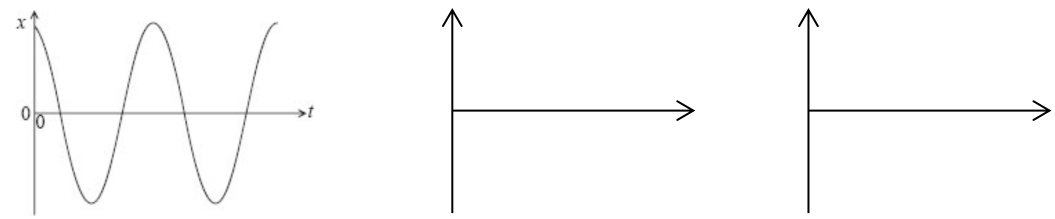
$E_T = \frac{1}{2} m\omega^2 x_0{}^2$

WHAT YOU SHOULD BE ABLE TO DO AT THE END OF THIS TOPIC

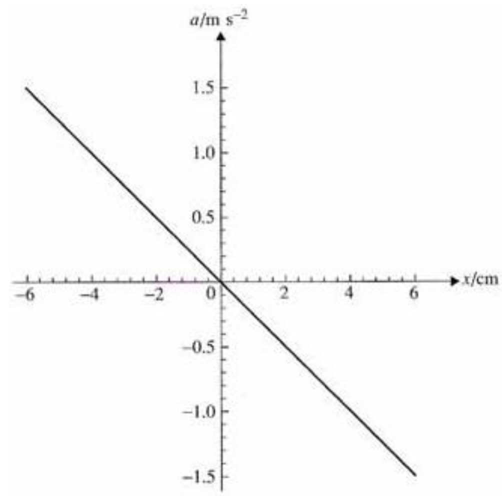
- □ Describe examples of oscillations and SHM through the defining equation of SHM
- □ Define the terms amplitude, displacement, angular frequency, frequency, period, and phase in the context of SHM.
- □ Apply and use the equations of SHM in different circumstances
- □ Discuss properties of SHM from graphs
- □ Recognize that in SHM there is a continuous transformation of energy, between KE and EPE
- □ Describe the effect of aperiodic external force and damping on an oscillating system
- □ Understand the meaning of resonance and give examples of its occurrence

HOMEWORK PROBLEMS:

1. The graph below the variation with time *t* of the displacement *x* of a particle undergoing simple harmonic motion. On the two blank graphs sketch the variation with time of the velocity *v* and the acceleration *a* of the particle.



2. The graph to the right shows the variation with displacement x of the acceleration a of a body.



a) Explain how it may be deduced that the body executes SHM.

b) Use the graph to determine the period of the oscillations. **[1.3 s]**

c) Determine the maximum speed of the body during the oscillations. **[0.30 ms^{-1}]**

3. The displacement of a particle executing SHM is given by y = 5.0cos(2t) where y is in millimeters and t is in seconds. Calculate:

a) the initial displacement of the particle. **[5.0 mm]**

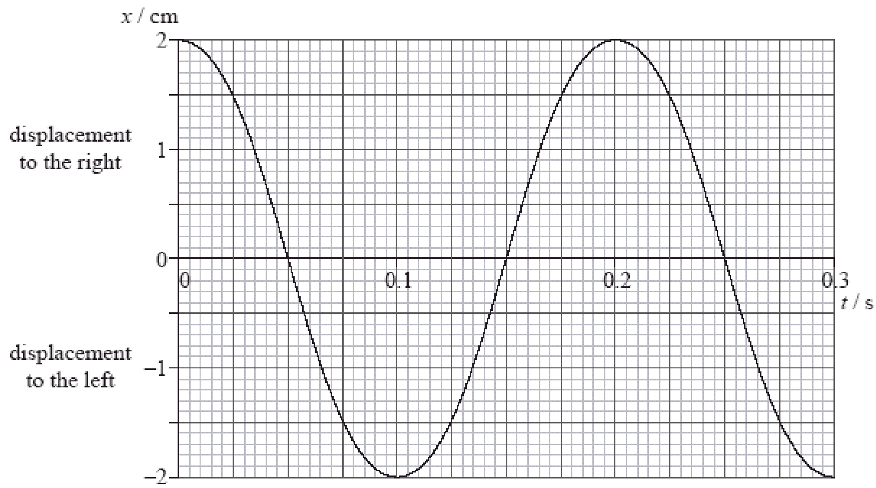
b) the displacement at t = 1.2 s. **[-3.7 mm]**

c) the time at which the displacement first becomes -2.0 mm. **[0.99 s]**

d) the displacement when the velocity of the particle is 6.0 mm s^{-1}. **[±4.0 mm]**

4. A longitudinal wave travels through a medium from left to right. Graph 1 shows the variation with time t of the displacement x of a particle P in the medium.

Graph 1



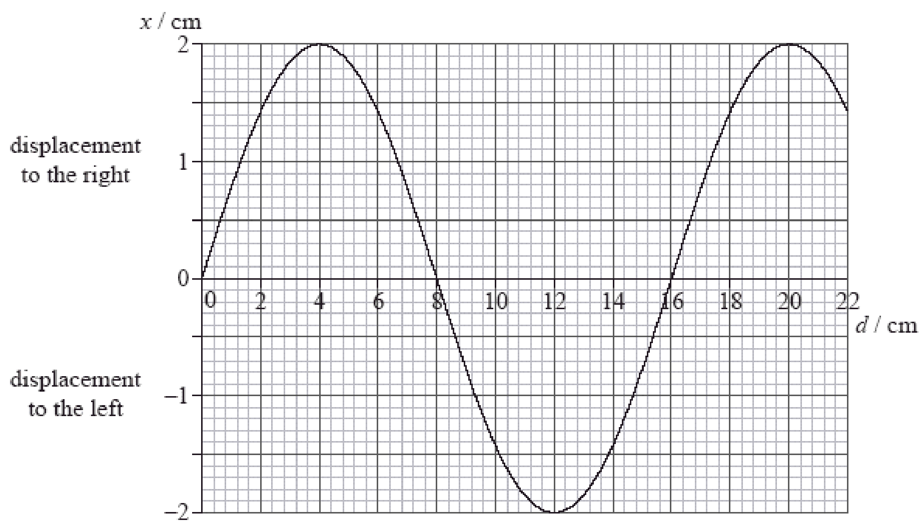
a) calculate the magnitude of the particle's maximum acceleration. **[20 m s^{-2}]**

b) calculate the particle's speed at t = 0.12 s. **[0.37 m s^{-1}]**

c) state the particle's direction of motion at t = 0.12 s. **[to the right]**

Graph 2 shows the variation with position d of the displacement x of particles in the medium at a particular instant of time.

Graph 2

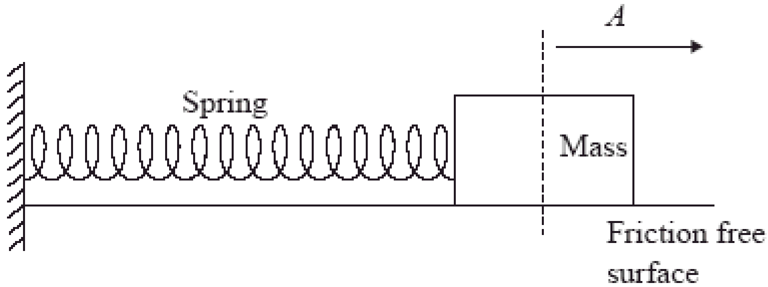


Determine for the longitudinal wave, using graph 1 and graph 2,

d) the frequency. **[5.0 Hz]**

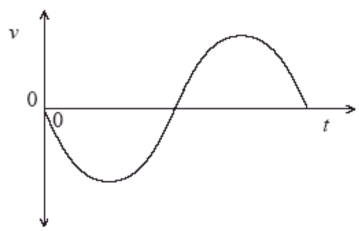
e) the speed. **[0.80 m s^{-1}]**

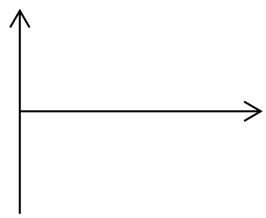
5. A mass on the end of a horizontal spring is displaced from its equilibrium position by a distance *A* and released. Its subsequent oscillations have total energy *E* and time period *T.*



An identical mass is attached to an identical spring. The maximum displacement is 2*A*. Assuming this spring obeys Hooke's law, determine the new time period and the total energy of the oscillations in terms of these given variables. **[T, 4E]**

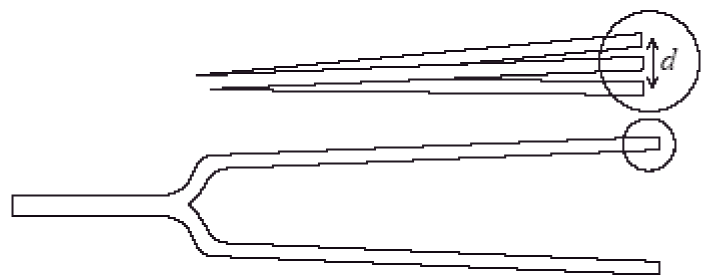
6. The graph shows how the velocity *v* of an object undergoing simple harmonic motion varies with time *t* for one complete period of oscillation. On the blank axis provided, sketch how the total energy E varies with time t.





7. A tuning fork is sounded and it is assumed that each tip vibrates with simple harmonic motion. The extreme positions of the oscillating tip of one fork are separated by a distance *d*.

a) State, in terms of *d*, the amplitude of vibration. **[d/2]**



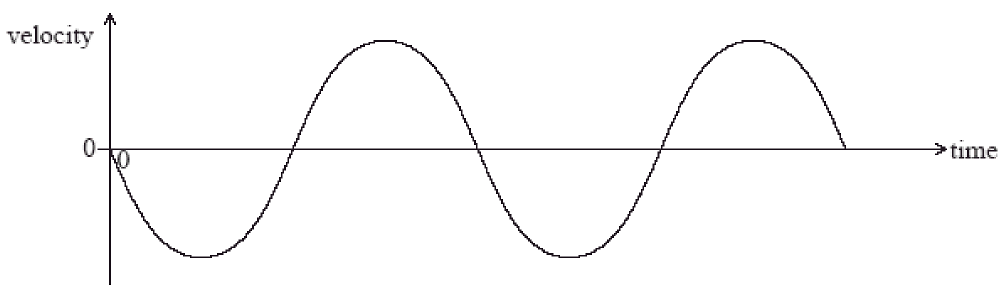
b) On the axes below, sketch a graph to show how the displacement of one tip of the tuning fork varies with time. On your graph, label the time period *T* and the amplitude *A*.

c) The frequency of oscillation of the tips is 440 Hz and the amplitude of oscillation of each tip is 1.2 mm. Determine the maximum

i) linear speed of a tip. **[3.3 ms $^{-1}$]**

ii) acceleration of a tip. **[9.2 x 10^{3} m s^{-2}]**

d) The sketch graph below shows how the velocity of a tip varies with time.



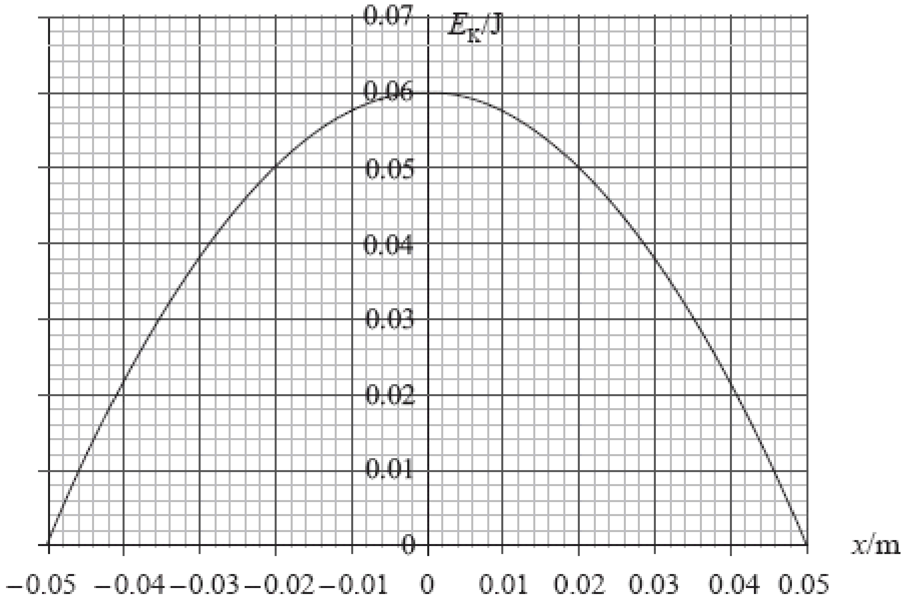
On the axes, sketch a graph to show how the acceleration of the tip varies with time.

e) In practice, the motion of the tips of the tuning fork is damped. Suggest **one** reason why the motion of the tips is damped.

8. A particle of mass *m* that is attached to a light spring is executing simple harmonic motion in a **horizontal direction**.

a) State the condition relating to the **net force** acting on the particle that is necessary for it to execute simple harmonic motion.

b) The graph shows how the kinetic energy E_K of the particle in (a) varies with the displacement x of the particle from equilibrium.



c) Using the axes above, sketch a graph to show how the **potential energy** of the particle varies with the displacement x.

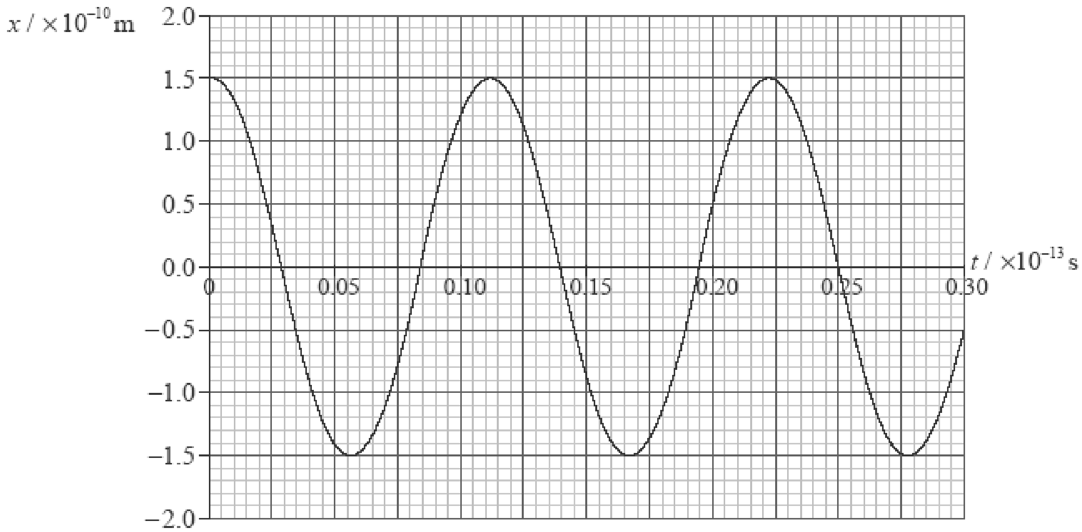
d) The mass of the particle is 0.30 kg. Use data from the graph to show that the frequency f of oscillation of the particle is 2.0 Hz.

e) The particles of a medium M_1 through which a transverse wave is travelling oscillate with the same frequency and amplitude as that of the particle in (b).

i) Describe, with reference to the propagation of energy through the medium, what is meant by a transverse wave.

ii) The speed of the wave is 0.80 m s^{-1}. Calculate the wavelength of the wave. **[0.40 m]**

9. In a simple model of a methane molecule, a hydrogen atom and the carbon atom can be regarded as two masses attached by a spring. A hydrogen atom is much less massive than the carbon atom such that any displacement of the carbon atom may be ignored. The graph below shows the variation with time t of the displacement x from its equilibrium position of a hydrogen atom in a molecule of methane.



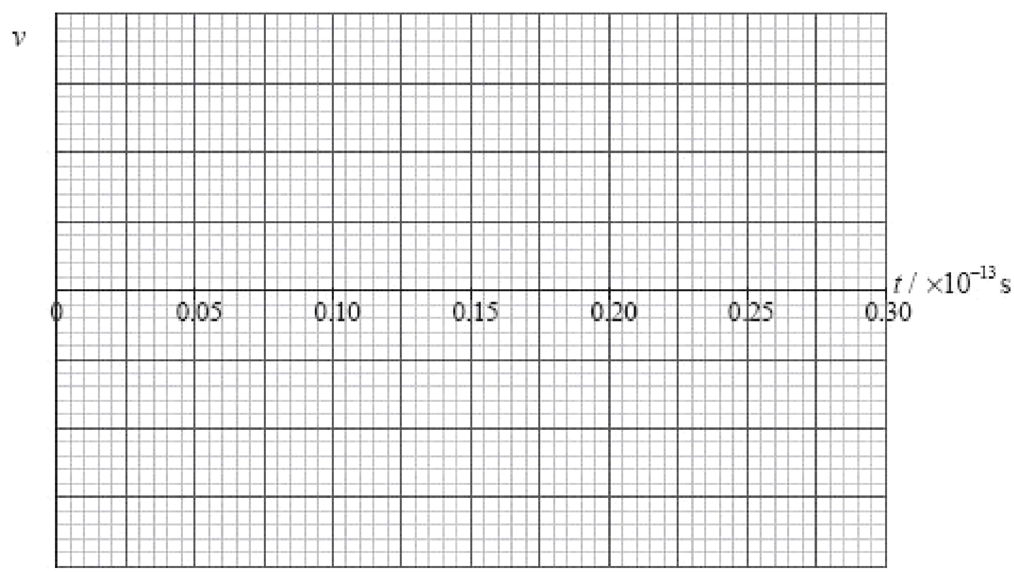
a) The mass of hydrogen atom is 1.7×10^{-27} kg. Use data from the graph above

i) to determine its amplitude of oscillation. **[1.5×10^{-10} m]**

ii) to show that the frequency of its oscillation is 9.1×10^{13} Hz.

iii) to show that the maximum kinetic energy of the hydrogen atom is 6.2×10^{-18} J.

b) On the grid, sketch a graph to show the variation with time *t* of the velocity *v* of the hydrogen atom for one period of oscillation starting at *t* = 0. (There is no need to add values to the velocity axis.)



c) Assuming that the motion of the hydrogen atom is simple harmonic, its frequency of oscillation f is given by the expression

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m_p}},$$

where k is the force per unit displacement between a hydrogen atom and the carbon atom and m_p is the mass of a proton.

i) Show that the value of k is approximately 560 N m^{-1}.

ii) Estimate, using your answer to (i), the maximum acceleration of the hydrogen atom.

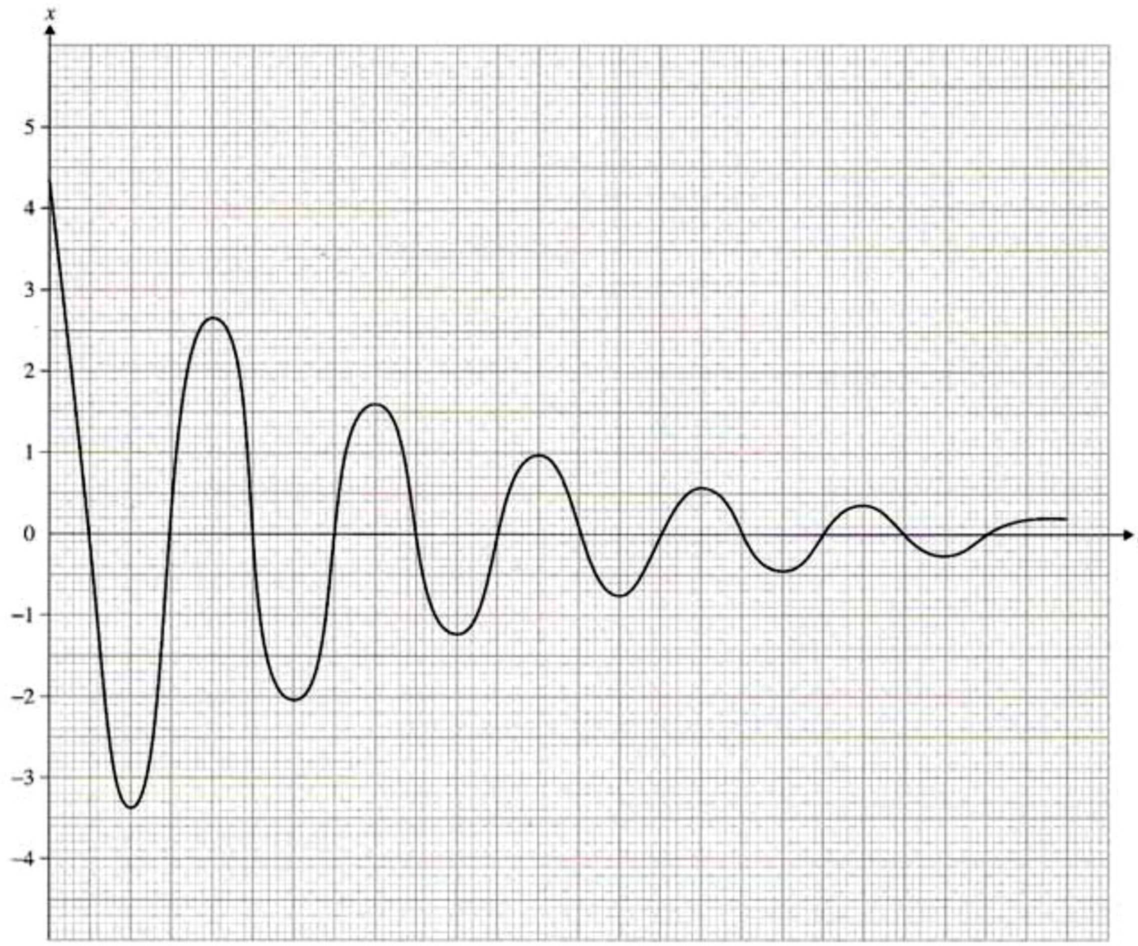
[5.0 x 10^{19} m s^{-2}]

d) Methane is classified as a **greenhouse gas**.

i) Discuss what is meant by a greenhouse gas (you may have to do some research on this one).

ii) Electromagnetic radiation of frequency 9.1 x10^{13} Hz is in the infrared region of the electromagnetic spectrum. Suggest, based on the information given in (a)(ii), why methane is classified as a greenhouse gas .

10. The graph shows the variation with time t of the displacement x of a particle undergoing SHM that is under-damped.



a) By making measurements on the diagram, determine whether the ratio of successive amplitudes stays constant.

b) The amount of energy stored in the oscillation is proportional to the square of the amplitude. Determine, for these oscillations, the amount of energy lost in one oscillation as a percentage of the energy stored in the previous oscillation.

c) On the same axes, draw a graph to show the changes, if any, to the variation of displacement if the amount of damping were to increase (but still keep the oscillations under-damped).